Modeling Open-Ocean Deep Convection

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LONG-TERM GOALS

To understand the convective process in the ocean, develop numerical models to study it, and so improve the representation of convection in ocean circulation models.

OBJECTIVES

To understand the relative importance of vertical mixing by convection and lateral advection by geostrophic eddies in setting the volume and properties of water-masses formed by intense winter storms blowing over the open ocean. The insights gained will inform and improve parametric representations of convection used in large-scale ocean models.

APPROACH

We are interpreting data gathered in the ONR Labrador Sea Convection Experiment, making use of process models of convection and a high-resolution model of the Labrador Sea developed at MIT.

We have developed non-hydrostatic, hydro-dynamical models exploiting parallel computational architectures and languages (see publications Marshall et al. [1997 a, b], Hill and Marshall [1996], Adcroft et al. [1997], Marshall et al. [1998]) that are capable of explicitly resolving the convective scale in the ocean. The model has been used to study convection modified by rotation in idealized settings; these have led to much insight into the nature of the convective process, have provided input to the planning of the field program, and are helping in the interpretation of the measurements that have been taken.

WORK COMPLETED

Four parallel strands of research have been pursued over the last year, all of which pertain to open-ocean convection and the interpretation of data taken in the Lab Sea experiment.

1. Computation of the Lagrangian statistics of float trajectories in a model simulation of a convecting and eddying ocean. These are being compared to the statistics observed by PALACE VCM floats deployed in the Lab Sea experiment in the winter of 1997 (in collaboration with Herbaut [LODYC], Davis and Lavender [SIO]).

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2. Simulation of the evolution of the convectively driven shallow mixed layers observed by autonomous underwater vehicles during the Lab Sea experiment in the winter of 1998 (in collaboration with Bellingham and Zhang [MIT]).
3. Simulation of the large-scale circulation of the Labrador Sea during 1997 and 1998 (in collaboration with Sheinbaum and Wunsch [MIT]) and preparation of model adjoint for assimilation studies.
4. Development of theoretical models of the patchiness of ocean convection using the tools of statistical fluid mechanics (in collaboration with Majda and DiBattista [Courant, NYU]).

RESULTS

Models of convection and ocean circulation developed at MIT, made possible by ONR's support, played a central role in the planning and execution of the field experiment conducted in the winters of 1997 and 1998. That model is now being used to interpret the data that was collected during the experiment. Two papers are in preparation: one that combines simulations of convection with AUV observations and the other that compares convection models with the Lagrangian statistics obtained from PALACE VCM floats. A paper has also been submitted to the Lab Sea JPO special volume describing a theory of the patchiness of open-ocean convection (see DiBattista et al. [1999], below) developed in collaboration with Majda at Courant.

IMPACT /APPLICATION

The research has had the following impacts:

- Led to the development of numerical methods and highly optimized parallel code for solution of the Incompressible Navier Stokes equations in the highly irregular geometries typical of ocean basins and marginal seas (see publications Adcroft et al. [1997], Hill and Marshall [1996], Marshall et al. [1997a], and Marshall et al. [1997b]).
- Applied maturing parallel architectures and languages to the numerical solution of the Navier Stokes equations (see publication Marshall et al. [1998]).
- Deepened our understanding of convection in the presence of rotation, and its role in the ocean circulation (see publications Jones and Marshall [1993], Jones and Marshall [1997], Klinger and Marshall [1995], Klinger et al. [1996], Legg and Marshall [1993], Marshall et al. [1994], Send and Marshall [1995], Visbeck et al. [1996a], Visbeck et al. [1996b], Whitehead et al. [1996]).
- Provided a theoretical and modeling context for the ONR 'Deep Convection' ARI in the Labrador Sea (see publications Wilcox et al. [1996] and DiBattista et al. [1999]).

TRANSITIONS

Our models and approaches are being used by an increasingly wide community, both at MIT and elsewhere. The MIT ocean model is the central tool of the NOPP consortium, ECCO, which draws together researchers from SIO, JPL, and MIT to develop a global state-estimation tool. Its non-hydrostatic capability is also being made use of in the NOPP Front project being led by Prof. Bogden at U. Conn. Our work on convection has led to numerous publications in the literature starting from the paradigms we have set out.

RELATED PROJECTS

1. The Labrador Sea Deep Convection Experiment
   http://www.ldeo.columbia.edu/~visbeck/labsea/labsea.html
2. MIT AUV development program
   http://seagrant.mit.edu/~auvlab/AUV_home.html
3. The NOPP front consortium
   http://nopp.uconn.edu/
4. The NOPP ECCO consortium

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